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ABSTRACT

Monitoring of the vital signs of casualties in the field is an ongoing concern of the Canadian Forces Medical System. A vital signs monitor has been developed, which would measure heart rate and body temperature continuously and concurrently. In order to enhance the capabilities of the device, it was decided to investigate the feasibility of adding blood pressure monitoring. Using the oscillographic method of measuring cuff pressures, and the Erlanger procedure for determining systolic and diastolic pressures, several algorithms were tested for determining blood pressure. A method of digitally sampling pressure pulses, using a two dimensional filter for determining pulse validity, and establishing systolic and diastolic blood pressure, is described.

RÉSUMÉ

La surveillance des signes vitaux des blessés est un sujet qui continue d'intéresser le Service de santé des Forces armées canadiennes. On a mis au point un appareil de mesure des signes vitaux, qui peut mesurer la fréquence cardiaque et la température corporelle de façon continue et simultanée. Dans le but d'accroître les capacités de cet appareil, on a décidé d'étudier la possibilité d'ajouter la surveillance de la pression artérielle. Grâce à la methode oscillographique de mesure de la pression au niveau du brassard et à la procédure Erlanger visant à déterminer la pression systolique et diastolique, plusieurs algorithmes ont été mis à l'épreuve en vue d'établir la pression artérielle. On décrit ci-après une méthode qui fait appel à des pouls calculés électroniquement, au moyen d'un filtre bidimensionnel servant à déterminer la validité du pouls et à mesurer la pression artérielle systolique et diastolique.

EXECUTIVE SUMMARY

As early as 1973, as a consequence of Trial CHACE (Casualty Handling in A Chemical Environment), it was found that sorting patients in protective ensembles into the appropriate evacuation priorities (triage) was difficult, because of the inability to obtain vital information such as pulse and blood pressure. The standard issue instruments for measuring heart rate and blood pressure could not be used without creating breaches in the casualty's protection.

A recent study determined the feasibility of using a microcontroller-based system to monitor heart rate and body temperature simultaneously, and continuously, in the field. Because the device was designed to allow for future expansion, the feasibility of integrating a blood pressure monitoring capability into the same device was investigated. No commercially available portable device was found that could monitor heart rate, body temperature, and blood pressure simultaneously. Many devices exist that measure heart rate and blood pressure but those known to the authors measure heart rate only while the blood pressure is being taken, i.e. not continuously.

The blood pressure measuring capability which has been added to the existing vital signs monitor is described. The new circuit converts the pressures in the blood pressure cuff into voltages compatible with microcontroller input requirements. The microcontroller software determines the validity of the voltage peaks, and analyzes peak to peak voltage (pressure) differences of interest. Once the cuff has deflated sufficiently, the pressures corresponding to the largest positive and negative differences are displayed as systolic and diastolic pressures respectively. Several error producing phenomena have been identified and algorithms have been developed to overcome them, such that blood pressures will be displayed more reliably, more often.

The device works well on a small number of local volunteers, but requires further evaluation on a larger number of human subjects, and in a clinical trial which would compare the measurements against an approved direct method. Several noisy environments in which this device might be used, have been identified, i.e. helicopters and vehicles used as field ambulances. More studies are recommended to quantify the possible interference these environments might have on the device, and make modifications to the design to lessen their effect. Following such modifications, prototypes of the complete vital signs monitor should be built in sufficient quantity for user evaluation.

1.0 INTRODUCTION

As early as 1973, as a consequence of Trial CHACE (Casualty Handling in A Chemical Environment), it was found that sorting patients in protective ensembles into the appropriate evacuation priorities (triage) was difficult, because of the inability to obtain vital information such as pulse and blood pressure. The standard issue instruments for measuring heart rate and blood pressure could not be used without creating breaches in the casualty's protection.

Investigations since then within the Canadian Department of National Defence have resulted in the development of several devices (1,2,3) which monitor heart rate of casualties in adverse environments such as within casualty bags employed in a chemical warfare (CW) environment. Since one of the early design criteria was to measure signs without compromising the casualty's protection (no skin contact allowed), the first heart rate monitors (1,2) employed microphones to pick up heart sounds through multi-layers of clothing. It was decided for reasons described below, to include an electronic stethoscope, which was a simple extension of the already existing electronics. Concurrently, a blood pressure clamp or sphygmoclamp (4) was developed, which could adapt the cuff of any existing blood pressure monitoring device to an arm, from the outside of a protective ensemble. Using the electronic stethoscope, also from outside the protection, blood pressures were measured. This did, however, necessitate the use of three devices (blood pressure monitor, electronic stethoscope, and a special clamp) to measure one vital sign. Because the reliability of the heart rate readings of this device was lower than anticipated, it was not accepted.

A more recent study (3) determined the feasibility of using a microcontroller-based system to monitor heart rate and body temperature simultaneously, and continuously. Upon the successful completion of that study, and because the device was designed to allow for future expansion, it was decided to investigate further the feasibility of integrating a blood pressure monitoring capability into the same device. No commercially available portable device was found that could monitor heart rate, body temperature, and blood pressure simultaneously. Many devices exist that measure heart rate and blood pressure but those known to the authors measure heart rate only while the blood pressure is being taken, i.e. not continuously. This report describes the work leading up to and including the development of a prototype microcontroller-based device for monitoring blood pressure in adverse field scenarios, and the integration of this capability with those of a previously designed device (3) to monitor heart rate and body temperature.

2.0 DESIGN CRITERIA

2.1 General

Since this study was an investigation of the feasibility of incorporating blood pressure monitoring into an existing device, it was necessary to review the overall design criteria. Although they have already been described elsewhere (3), the design criteria are repeated here for clarity:

a. rugged construction yet compact and light for use in all likely operational situations;

b. long shelf life (minimum 10 years);

c. capable of being operated by a medical assistant without extended training periods;

d. one size must fit all male or female adults and be as non-invasive as practical;

e. powered by rechargeable batteries with an endurance of at least twelve hours and, as a back up, be alternatively powered by other batteries (e.g. alkali) in the supply net;

f. alarm functions must be audible and visual, be capable of being switched off, and must warn of low battery power;

g. monitored parameters should be displayed digitally and be readable in dark or other adverse conditions;

h. the power source must be isolated, eliminating the possibility of injuring the patient;

j. the reliability of the components is an important feature and resupply of individual components is much preferred to total unit replacement;

k. since this device will have wide application, many units will be required, therefore cost must be as low as possible ($200 - $400 range or lower); and

m. environmental operating parameters consist of the following:

   i. storage and operating temperature range -40°C to +50°C,

   ii. humidity operating range 0-95% R.H.,

iii. not effected by the range of electromagnetic interference normally associated with aircraft or other machinery,

iv. stable in pressure reductions of up to 10,000 feet (523 mmHg),

v. water resistant (waterproof desirable),

vi. impervious to or at least unaffected by the usual chemicals and toxins that could be used in chemical or biological warfare (CW or BW), and

vii. the operation or connections of the monitor must not compromise the isolation of a patient exposed to chemical or biological assault.

2.2 Blood Pressure

Once a casualty wearing a protective ensemble reaches an aid station, he will be examined by a triage officer. Depending on the circumstances with respect to contamination, he may either continue to wear his ensemble or be placed in a casualty bag. This would be the earliest stage when the vital signs monitor transducers could be applied. With respect to blood pressure monitoring, a cuff would be placed around the arm when convenient to do so, and the air tube (along with the temperature probe and heart rate leads) would be passed through the small opening created by the meeting of the zippers of the CW suit or the casualty bag.

It is estimated that the range of blood pressures to be measured with the device would be 50-200 mmHg, and it was decided that the values, once acquired, should be displayed such that both systolic and diastolic pressures could be read simultaneously. Audible and visual alarms for blood pressures are not required. Since it is envisioned that one person may wish to monitor a number of seriously ill and isolated patients from a single static position, the capability of being actuated from distances of up to ten feet should be investigated. An example would be the monitoring of four patients located in the back of an ambulance, from the drivers cab.

3.0 METHODS AND MATERIALS

3.1 Background

A vital signs monitor (VSM) which measures heart rate and body temperature continuously (3) has been designed, built, and tested. The design was such that future expansion, such as the monitoring of other vital signs, would be possible. The possibility of using the resources remaining in the vital signs monitor previously developed, to integrate a blood pressure monitoring capability was investigated. Aspects of blood pressure monitoring are reviewed to support the method of measurement implemented. The hardware and resources available in the VSM are then described, followed by a more detailed description of the signal conditioning and software development.

3.2 Methods of Blood Pressure Measurement

The available non-invasive methods for taking systolic and diastolic pressure readings include the auscultation method, the oscillometric method, and the ultrasonic method. Palpatory and flush methods have been excluded from this discussion as it is very difficult if not impossible to measure a diastolic pressure using these methods. Implementations of each of these methods exist commercially, and there are even devices available which combine the advantages of more than one method, in order to obtain more accurate results. All of the methods, however, require an inflatable cuff, a means of inflating the cuff, a means of deflating the cuff, an appropriate transducer, and an algorithm for determining systole and diastole.

When considering the means of inflating and deflating the cuff, the options include automatic, semi-automatic, and manual devices. The automatic method uses an electric pump to inflate the cuff to a predetermined suprasystolic pressure, then allows the cuff to deflate at a constant rate generally accepted to be about 2-4 mmHg per second, during which time, measurements are made. The manual method requires a person to inflate the cuff, then open a valve to allow the pressure to bleed at the rate mentioned above. The bleed rate is subjective i.e. estimated. The semi-automatic method adopts the advantages of both of the other methods, and was the method of choice for this device. The operator inflates the cuff manually, eliminating the need for a power-hungry, noisy, and expensive pump, and the preset pressure relief valve automatically deflates the cuff at the proper rate.

The transducer and the manner in which systolic and diastolic pressures are determined from its output, are the best ways of distinguishing between the three main methods previously listed. The auscultation method of taking blood pressure employs a sound transducer or microphone to detect Korotkoff sounds. The sensor is either placed inside the distal end of the cuff and electronically

monitored, or placed on the cubital fossa and sensed with human ears (stethoscope). The pressure at which the Korotkoff sounds appear marks systole while the pressure at which the sounds disappear marks diastole. Much controversy exists with respect to the exact sound on which to base diastole (6). Electronically, the pressure in the cuff is monitored via a solid state pressure transducer. When the appropriate Korotkoff sound appears or disappears, the pressure is read and displayed. Using the stethoscope, a person typically watches an aneroid pressure gauge and makes a mental note of the systolic and diastolic pressures at the appropriate moments. Although this method is simple, and well known and accepted, it does require a sound transducer being accurately placed over the brachial artery, is very susceptible to ambient noise (5), and does not work well on patients in shock.

The oscillographic method employs no other sensor than a solid state pressure transducer to which the cuff is attached. Since pressures are detected as opposed to sounds, shock does not prevent the measurement of blood pressure, and since there is no requirement to place a sensor precisely over a specific anatomical location, the cuff can be applied quickly, even at non-standard locations (e.g. thigh, calf or forearm). As the cuff pressure decreases from a suprasystolic to subdiastolic pressure, pulses of increasing, then decreasing amplitude are superimposed on the decreasing cuff pressure signal. These pulses are caused by blood movement beneath the cuff, and can be used to determine the systolic and diastolic pressure. The pressure where greatest increase in pulse amplitude occurs corresponds to the systolic pressure, and the pressure where the greatest decrease in pulse amplitude occurs (after the maximum oscillations) is the diastolic pressure (7). The mean arterial pressure is chosen as the lowest cuff pressure at which the maximum oscillations occur (8,9).

The ultrasonic method employs an ultrasonic sensor placed carefully over the brachial artery distal to the cuff. The sensor consists of an ultrasonic transmitter and a receiver whose associated circuitry compares reflected frequencies with those transmitted. The frequencies of ultrasonic waves reflected from moving soft-tissue or blood, are shifted in proportion to their velocity (Doppler effect). Systolic blood pressure can be estimated by noting when blood first starts to flow distal to the cuff. Movement of the arterial wall can be used to estimate diastolic pressure. Although systolic pressures can be obtained more accurately with these devices, their main disadvantages are their inability to easily record diastolic pressures, their dependence on proper placement, their fragility, and their cost.

These various methods have been compared to direct methods, and to each other with varied results. None of the indirect methods for determining systolic and diastolic blood pressures produce values equal to those taken by direct methods, which are assumed to be the most accurate interpretations of actual arterial pressures.

All indirect methods seem to yield higher blood pressures, but not consistently. Some authors (10, 11, 12) who have compared the various methods, have concluded that oscillography gave results nearest those of the direct methods. Others (13) have compared oscillography on the arm (using a Dinamap device) with counterpressures, or the Penaz technique, in the finger (using a Finapres device) and showed the former is more accurate and more reliable. Researchers (14) have also evaluated more than one type of device employing oscillography on the finger and have concluded that this type of measurement is not recommended for routine use. It is the opinion of these authors, that the finger is not the position of choice for blood pressure measurement. A principle reason is the likelihood of reduced or arrested blood flow in the peripheries for a variety of reasons, e.g. cardiovascular shutdown occurring as the result of exposures to cold temperatures.

The oscillographic method of obtaining blood pressure was chosen for this study, because it can yield the most accurate determination of arterial pressures, is already widely used and accepted, is simple in design by using the cuff as the only transducer, and has the advantage of being adapted to various non-standard locations on the body. Compared with the method described in the introduction (Sphygmoclamp, etc.), using oscillography reduces the number of devices required for taking the blood pressure from three to one.

3.3 The Sensor

The transducer used to measure cuff pressures was a Motorola MPX5050, which has internal signal conditioning to give outputs particularly suited for microprocessor based systems. Its pressure range is given as 0-370 mmHg ±0.2% full scale. Pressure applied to the positive pressure side is measured against the ambient atmospheric pressure applied to the vacuum side through the vent hole in the housing of the differential pressure sensor element. It is temperature compensated, such that the maximum error over the full temperature range (-20°C to +40°C) and pressure range does not exceed 1.0%. It is also a low power device, such that at a supply voltage of 5.0 Vdc, the supply current is approximately 8.0 mAdc.

3.4 The Microcontroller and Display

The selection process of an appropriate microcontroller and display for the VSM has been reported elsewhere (3). A low power (CMOS) Motorola 68HC805B6 (see Annex A for a complete list of features) makes up the central processing unit in the existing device. The display currently being used is 16 characters wide by 2 lines (enough space to display heart rate, body temperature, systolic and diastolic pressures simultaneously), interfaced directly to the microcontroller via 11 digital I/O lines. The lower operating temperature criterion of -40°C (see Design Criteria) was compromised in the selection of the display, because an LED (light

emitting diode) display meeting that criterion would require too much power. A low power LCD (liquid crystal display) with an operating temperature of -20°C was considered adequate and required fewer batteries (size, weight and endurance consideration).

For development purposes, the microcontroller mentioned above uses erasable program memory to facilitate easier development. It is anticipated that the final product (final program) will incorporate a non-erasable memory. This would again be a movement towards a rugged design and low cost. With respect to the microcontroller configuration (not including the blood pressure monitoring capability), only one of eight A/D ports and fourteen of twenty-four I/O ports have been used. The software took up a little less than 2 kbytes of the available 6 kbytes of on-board memory, thus allowing for expansion of its capabilities.

3.5 Signal Conditioning

Basic signal conditioning wasa used to convert the raw output of the pressure transducer into signals compatible with the microcontroller. A block diagram of the general method used to condition cuff pressures is illustrated in figure 1.

A standard blood pressure cuff, complete with inflating bulb and automatically-deflating valve assembly, is connected to the pressure sensor. The rated output voltage range of the sensor is 0.5 to 4.5 Vdc, of which a range of 0.50 to 3.19 Vdc is used, which corresponds to pressures of 16 to 255 ±1 mmHg (the selected operating range of this device). During a normal measurement of blood pressure, the sensor detects a sharp rise in cuff pressure (inflation phase), followed by a slowly decreasing ramp (deflation phase) (see figure 1).

Superimposed on the decreasing pressure ramp are the individual pulse pressure peaks of varying height which correspond to heart beats. Proper height measurement of these peaks (magnified in figure 1) is of critical importance because their amplitude is used as the basis of blood pressure determination. A high pass filter with a frequency cutoff of 0.8 Hz was used to separate the peaks from the decreasing ramp, allowing the faster pressure peaks to pass while filtering out the slower deflating pressure ramp. The small resulting signal was then amplified (gain=10). The voltage signal at this point contained too much electrical noise. This was reduced using a bandpass filter (1.6 Hz to 9.6 Hz). The signal was again amplified (gain=40) in preparation for the next stage.

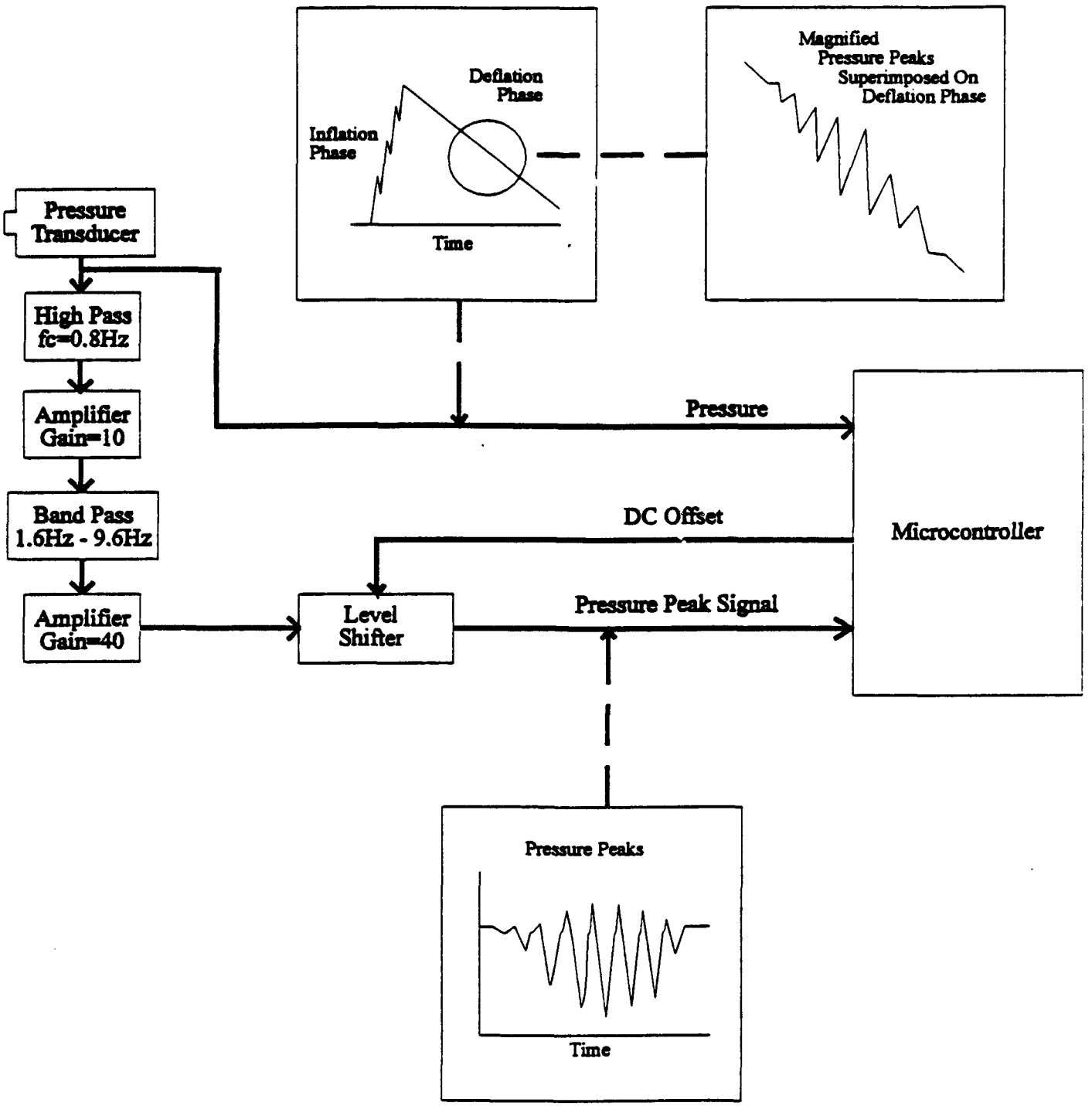

Figure 1. Block diagram of the blood pressure measuring system.

As will be discussed later, the software identifies the signal peak-to-peak heights. In order to make the best possible peak-to-peak measurements, the signal is centred in the microcontroller input range (0-5V). Typically, the largest peak following the 40x amplifier is approximately 60% of the input range. Once the low and high points of the signal have been determined, the microcontroller sends out an appropriate DC offset signal to a level shifter, which biases the signal up or down so that it remains fully within the A/D input limits. As long as the peak-to-peak value is less than 5V, there will be no clipping. Also, once the peak has been validated, the microcontroller sends a separate signal to a LED, as a visual confirmation that a valid peak has been detected.

For various reasons, e.g. determination of inflation and deflation phases, systole, diastole, etc., cuff pressure must be monitored. As a consequence, the raw sensor output is fed directly into one of the microcontroller A/D inputs.

Figure 2 is the hardware implementation of the block diagram.

3.6 Software Development

A software method of digitally sampling pressure pulses, using a two dimensional filter for determining pulse validity, and establishing systolic and diastolic blood pressure, is described.

Figures 3, 4, 5 and 6 contain the flow charts of the algorithm used to determine the blood pressure. Figure 3 describes one part of the program (program C), while figures 4, 5 and 6 collectively comprise the flow chart of another part of the program (program D). These two programs run in parallel once program D is activated by program C. The length of the actual program code precludes it being included in this report.

Program C looks at the pressure signal every 0.262 s (timer interrupt). If the pressure is increasing, it is assumed that the operator has started inflating the cuff. Once program C detects that the inflation trend has stopped and deflation has begun, it activates program D, which looks at the pressure peak signal every 15 ms. Program D finds the pressure peaks, measures their heights, and subsequently determines if the pressure value being supplied by program C is the systolic pressure or diastolic pressure.

In more detail, program C can be considered the controlling program. It detects the various phases of a blood pressure measurement cycle i.e. resting, inflation, deflation, and termination. The resting phase is defined as the time between the end of a deflation phase (cuff pressure <16 mmHg), and the beginning of an inflation phase (cuff pressure >16 mmHg), during which the program is in a wait state.

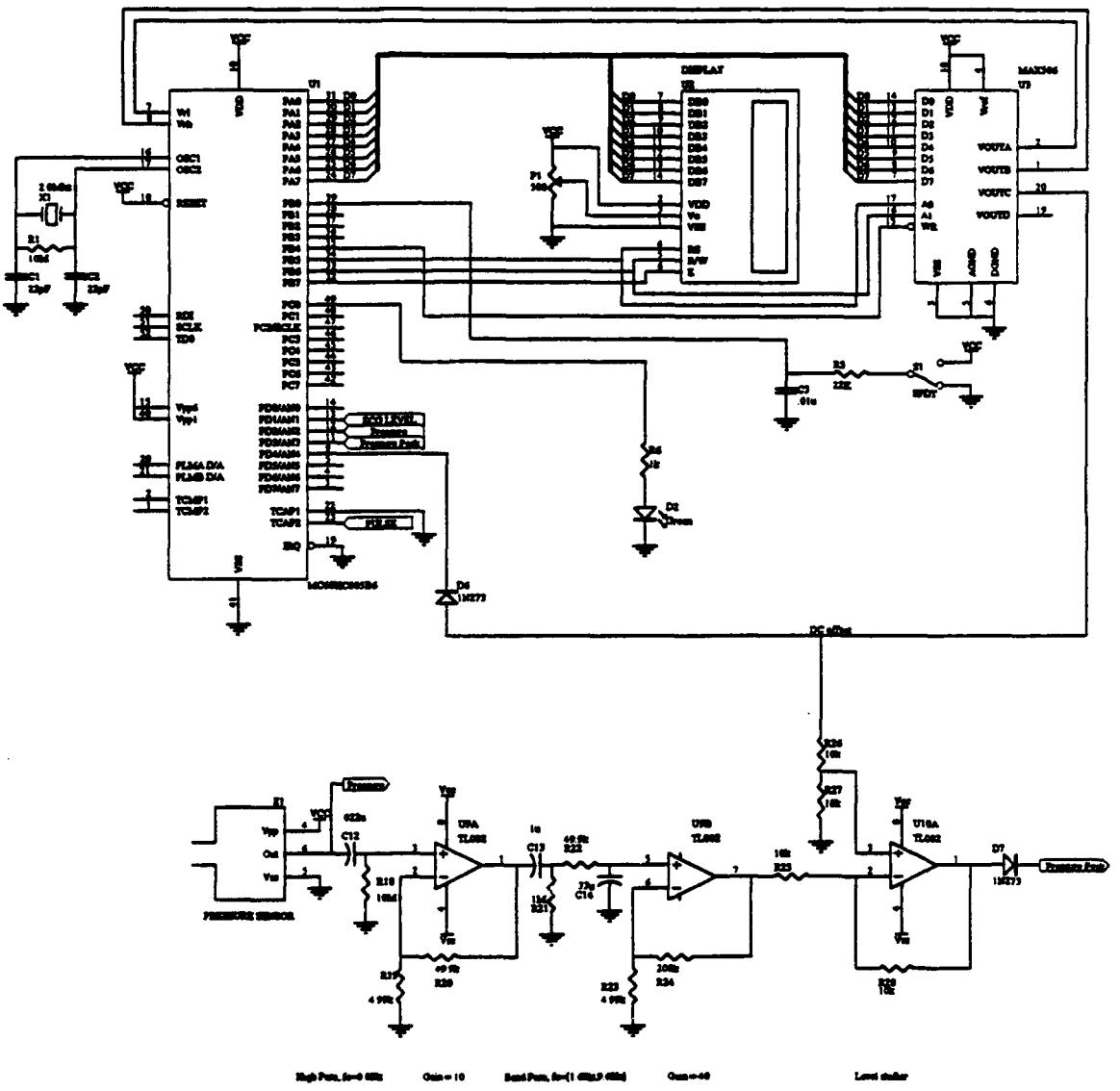

Figure 2. Schematic of the signal conditioning circuit.

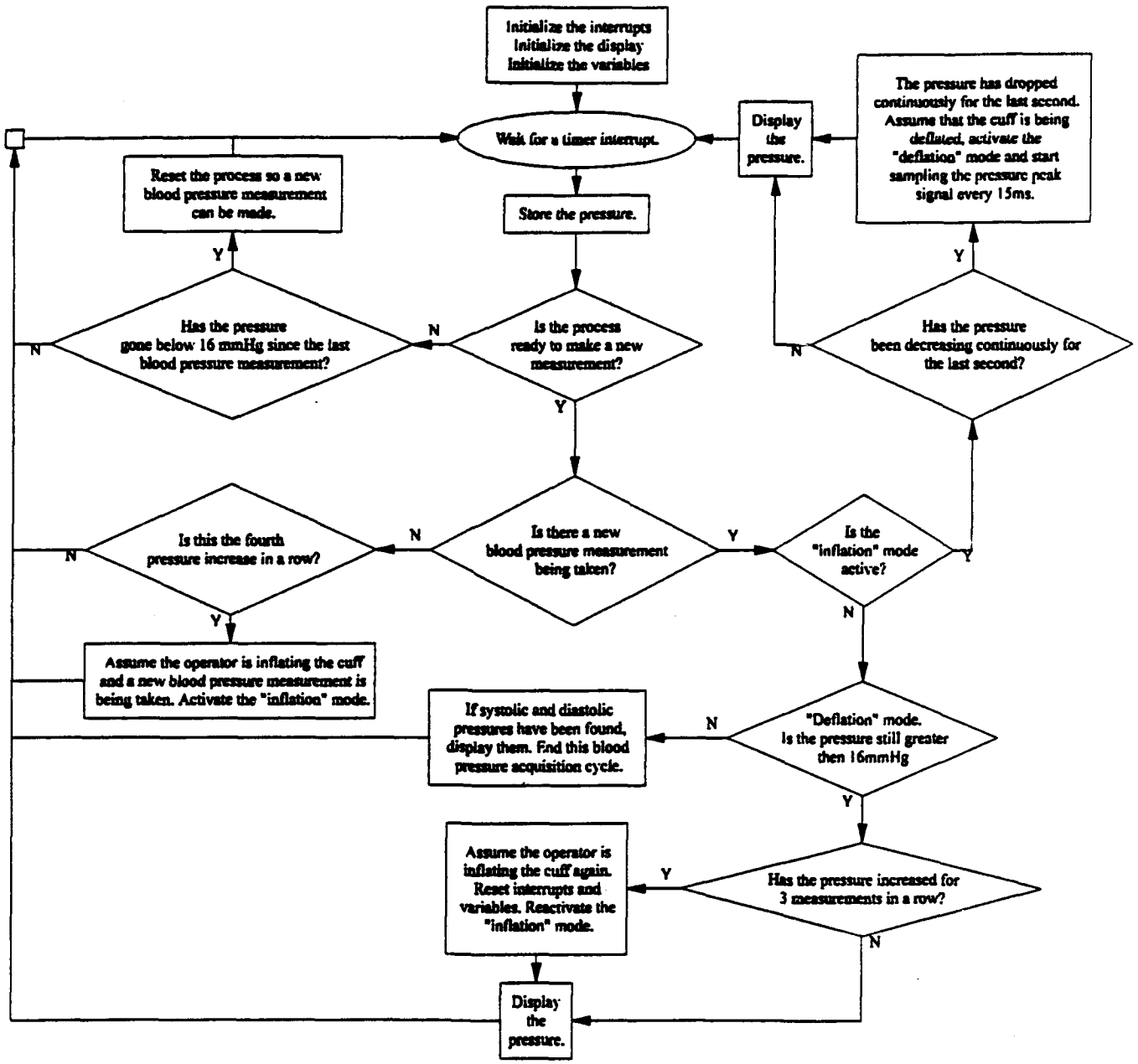

Figure 3. Flow chart of program C, the controlling program.

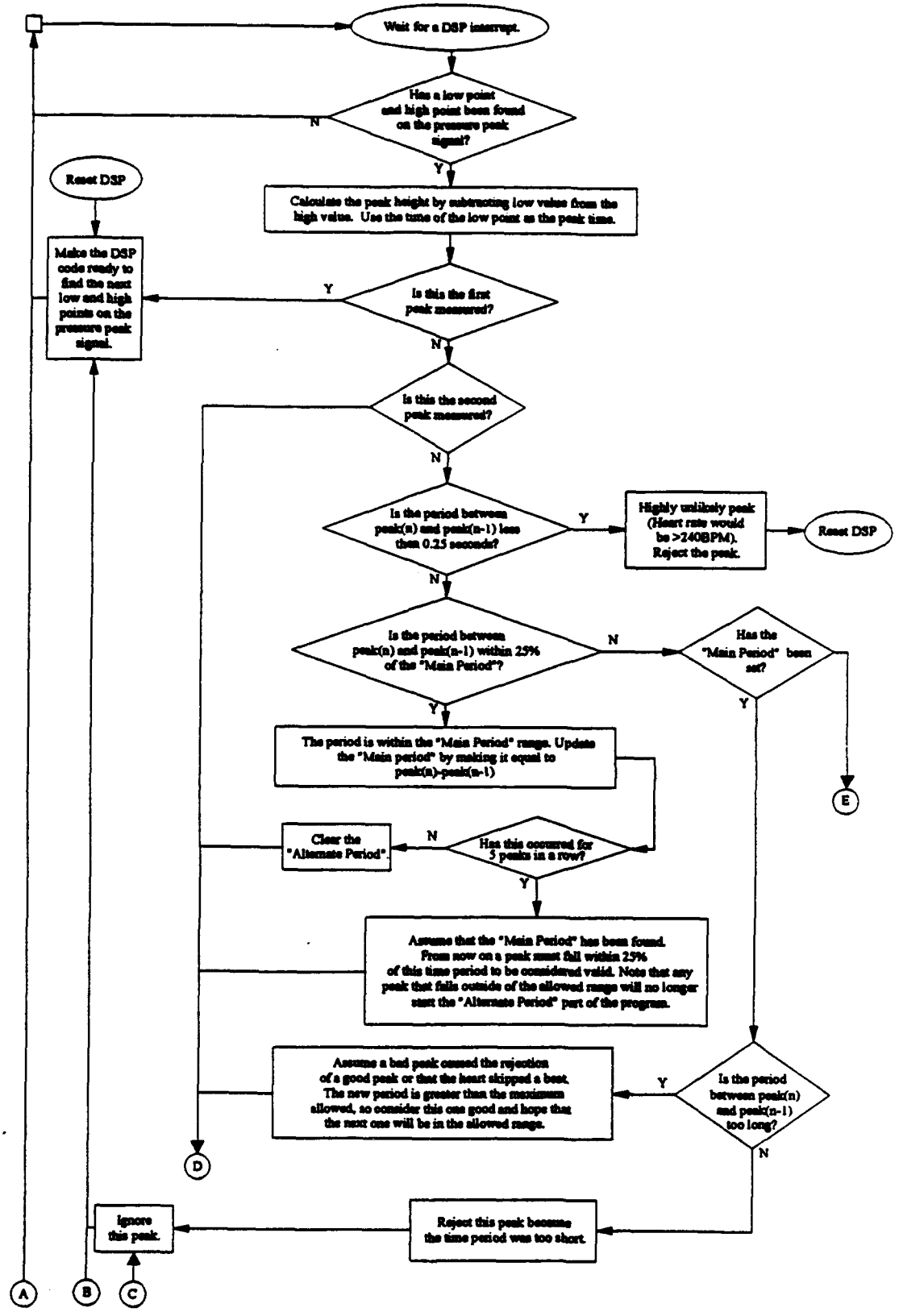

Figure 4. Flow chart of the first of three sections of program D, which collectively determine the blood pressure.

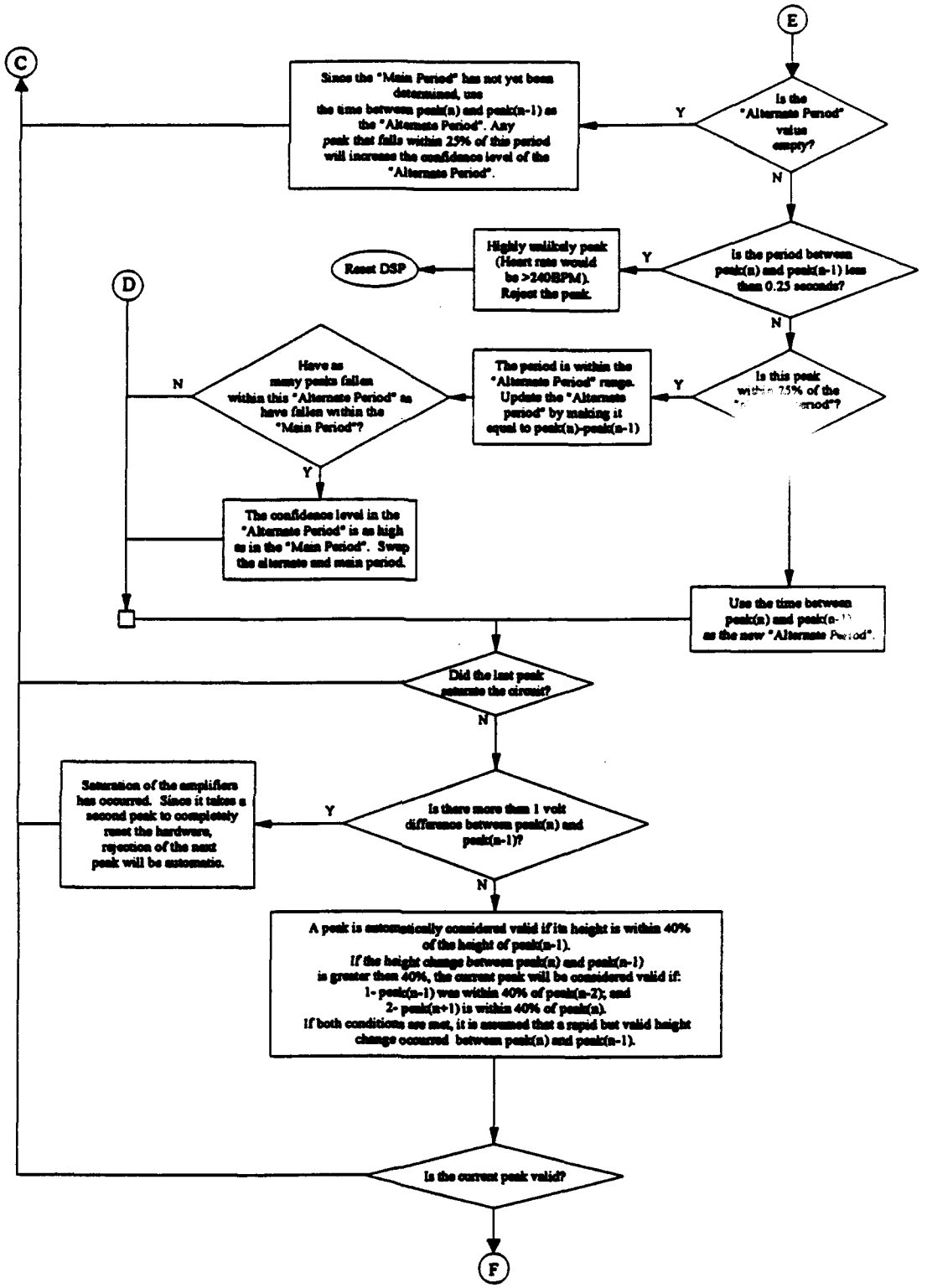

Figure 5. Flow chart of the second of three sections of program D, which collectively determine the blood pressure.

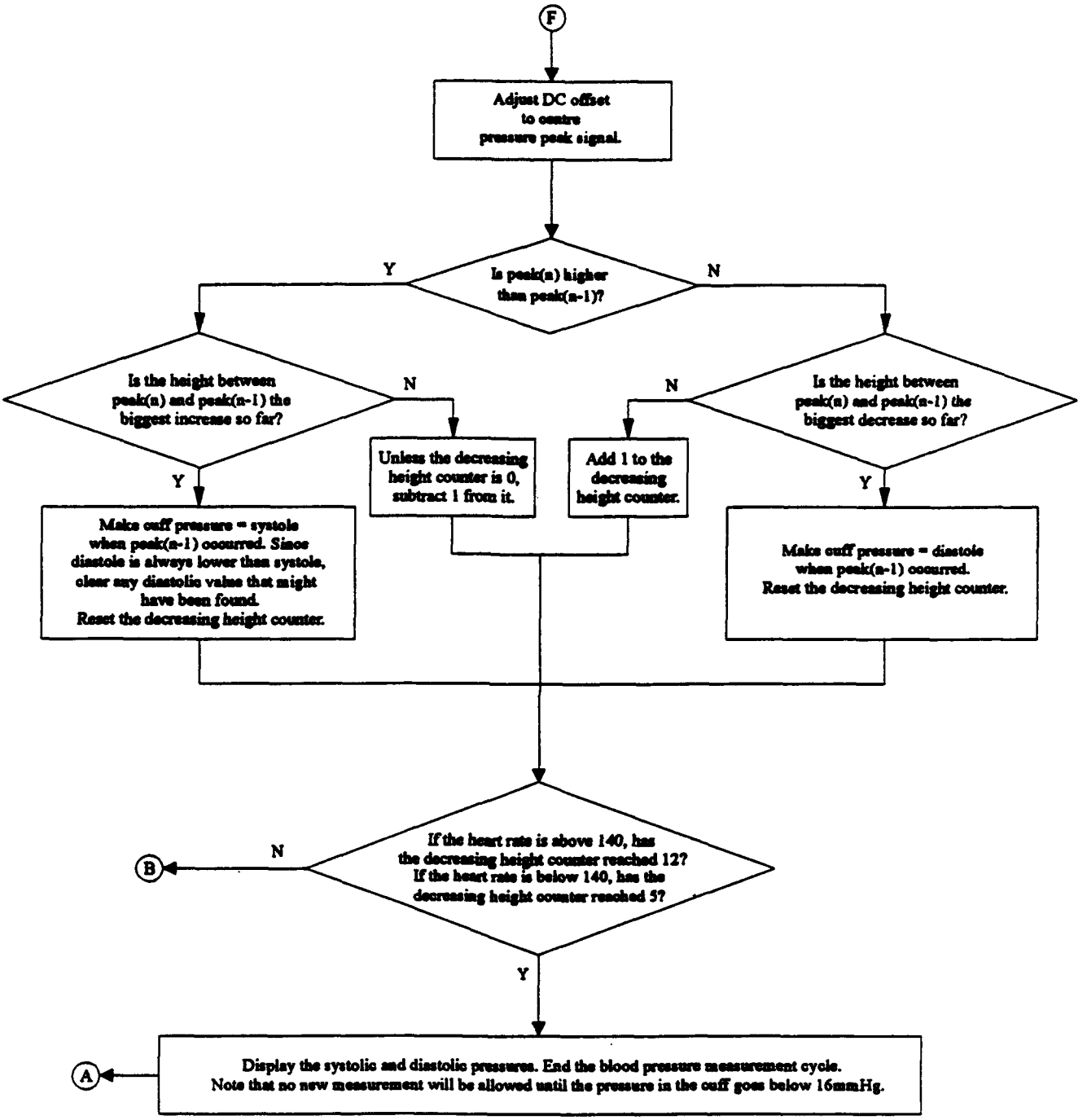

Figure 6. Flow chart of the third of three sections of program D, which collectively determine the blood pressure.

The inflation phase can only start when the cuff is fully deflated (cuff pressure <16 mmHg). Cuff pressure exceeding 16 mmHg and followed by four measurements of increasing values, is interpreted by program C as the beginning of the inflation phase. These criteria prevent a muscle spasm, or other artifact that causes a short pressure rise and fall, from activating the blood pressure cycle.

After the cuff has been inflated, the deflation phase follows. Program C interprets the onset of deflation, by four consecutive samples of the pressure signal, decreasing in value i.e. the cuff pressure has been decreasing for 1 s. This will prevent short pauses in the inflation stage erroneously activating the deflation stage. If the measured pressure is lower than 16 mmHg, the cuff is considered fully deflated, and back in a resting phase.

Provision for ending the blood pressure measurement cycle, or termination phase, is present in both Programs C and D. In program C, the blood pressure cycle is terminated when the pressure falls below 16 mmHg while in the deflation stage. In program D, a counter is incremented (confidence level) with each new peak following the determination of a diastolic pressure. Once a certain number (5 for heart rate <140; 12 for heart rate >140) of peaks have been counted and the diastolic pressure has not changed since the count began, the value is displayed and the blood pressure measurement cycle is ended.

Returning to the inflation phase from the deflation phase has also been implemented. This is necessary for two reasons. One reason is when a long pause during inflation erroneously triggers the deflation stage and the operator continues to inflate. The other reason is when the operator realises part way through deflation that the cuff was not inflated high enough. The criterium for returning to the inflation stage from the deflation stage is that three consecutive pressure increases are measured.

Program D (figures 4, 5, and 6) is the portion of the program which actually determines the systolic and diastolic blood pressure values. Since a large part of the flow chart describes how the program deals with situations when something unexpected happens, the approach used to describe the program is to consider the situation when nothing unexpected happens. This will be followed by a discussion of how the rest of the program validates each peak as a blood pressure peak.

Sampling of the pressure peak signal is begun once the main program has determined that the cuff is deflating. Successive high points and low points on the pulse wave are determined, and peak heights are calculated. Assuming peak heights have been determined for several peaks, and the signals are clean and steady, then all those peaks will have been classified as "valid peaks" (bottom of figure 5). Each new peak height is compared to the previous peak

height (figure 6) and the difference is recorded as an increase or a decrease. First, the largest increase is found, and then the largest decrease, which correspond to systole and diastole (7). If the envelope of the pressure peaks resembles a bell-shaped curve (ideal), this determination is straightforward. If, however, as is often the case, the envelope more closely resembles a small sinusoid superimposed on a bell-shaped curve, it is possible to register an increase, then a decrease, then an increase in peak height. Theoretically, it would therefore be possible to determine a diastolic pressure before a systolic pressure. Because this is impossible, once any new systolic pressure is determined, the diastolic variable is cleared. The "height counter" has been added to allow the processor to define an end point to the measurement. If the appropriate count is obtained, no further calculations are made, even if the cuff pressure is still above 16 mmHg (forces the "N" path in the "ready to make a new measurement" determination in figure 3).

The portion of the program (figures 4 and 5) between the calculation of a peak height and the comparison of it with the previous one, tests the peaks as they are calculated and decides on their validity. This section increases the reliability of the readings by ignoring as many of the definable error peaks as feasible. Using a digital oscilloscope, erroneous peaks were observed and noted. They usually fell into one of two general categories: they were the wrong height or occurred at the wrong time. A two dimensional filter was developed which would test the peaks for amplitude and period i.e. must be ±40% of the previous peak height, and ±25% of the previous period between peaks. Extremes were treated as special cases. If the peak saturated the input, two peaks would be ignored before a new peak was tested. If its period was less than that of the upper limit of heart rate of the device, it would be ignored.

If the legitimate pressure peaks could be identified, the test parameters for period and amplitude would be simple. The challenge was to identify the legitimate peaks in the presence of possible error peaks. It was assumed that usually, valid peaks would outnumber invalid peaks. When a new blood pressure measurement starts, the first number of peaks are monitored and their heights and their periods are compared. Five repetitions of periods within 25% of one another would determine the period of the heart rate, and all succeeding peaks must be within 25% of this rate to be considered valid. To account for the possibility that the first period measured might be the wrong period, it was decided to track two heart rate periods, a main period and an alternate period. The first of the two periods to reach five repetitions is registered as 'the' heart rate period.

After the peaks are checked for period, they are checked for height. The simple procedure is that the current peak must be within 40% of the previous peak. If it is larger, it is not

immediately discarded, however. If the last two peaks met the criterium, and the next peak is within 40% of the current one, then it is assumed that a rapid but valid peak height change has occurred.

Once a pressure peak is validated, two other events are initiated. The height information is also processed to determine the voltage bias required to centre that peak at the microcontroller input. This information is converted to an appropriate voltage level, and sent to the level shifter (figures 1, 2 and 6) so the likelihood that the next peak will appear between the input limits is higher. The other event triggered by a valid peak is a voltage signal sent by the microcontroller to a LED, to give the operator a visual indication of heart beats as detected by the blood pressure cuff. This is simply designed as another check to ascertain if the system is operating properly in the field.

4.0 Discussion and Results

A prototype of the design including both the signal conditioning circuit and software development was assembled. Both systolic and diastolic blood pressures were illustrated on the two lines of the display. A digital oscilloscope (Philips PM3320A) was used to give a visual display of the pressure peaks appearing at the input to the microcontroller and many blood pressure measurements were taken of three individuals. Using the Erlanger method of determining systole and diastole mentioned previously, and assuming the cuff pressure determinations were accurate, blood pressure was determined on the oscilloscope and then compared to the monitor display. More evidence was gathered with respect to what phenomena caused erroneous displays. These phenomena were almost always the result of spurious peaks created by the cuff (e.g. physically being bumped) or by the arm (e.g. being flexed). A two-dimensional filter was introduced into the algorithm, whereby the period and amplitude of a peak were predicted and compared to the actual values, to test the validity of the peak. If the peak was not valid, it was ignored. The final version of the program appears to function accurately (with respect to oscilloscope readings) and reliably (infrequent errors displayed).

The design criteria were used as guidelines in the development of the signal conditioning circuit. Constant attention was focused on maintaining a low component count to lend ruggedness and compactness to the design, and keep the cost down. Low power consumption, long shelf life, and environmental operating characteristics (least affected by temperature, humidity, and pressure), were very important considerations in component and design selection. The lower operating temperature criterion of -40°C was changed to -20°C in the selection of the display, because it was decided that an LCD display using less power was more important than an operating temperature of -40°C.

In the previously developed monitor (3), the only external controls were an on/off switch, and a switch to reset the audible alarms, allowing anyone to operate the device without extended training periods. This has not changed.

In summary, a blood pressure measuring system has been added to an existing vital signs monitor. The new circuit converts the pressures in the blood pressure cuff into voltages compatible with microcontroller input requirements. The microcontroller software determines the validity of the voltage peaks, and analyzes peak to peak voltage (pressure) differences of interest. Once the cuff has deflated sufficiently, the pressures corresponding to the largest positive and negative differences are displayed as systolic and diastolic pressures respectively.

With the inclusion of this new hardware and software, and with respect to the microcontroller configuration, there are only five out of eight A/D ports and eighteen out of twenty-four I/O ports allocated thus far. The current software (heart rate, body temperature and blood pressure) takes up approximately 2.7 kbytes out of the available 6 kbytes of on-board memory, thus allowing for even more future expansion.

5.0 Conclusions and Recommendations

A blood pressure monitor capable of monitoring systolic and diastolic pressures in the field under adverse, unconventional conditions, is described. Several error producing phenomena have been identified and algorithms have been developed to overcome them, such that blood pressures will be displayed more reliably, more often. The device works well on a small number of local volunteers, but requires further evaluation on a larger number of human subjects, and in a clinical trial which would compare the measurements against an approved direct method. Because not all possible electronic conflicts between each vital sign determination have been investigated, further work is also required to integrate the blood pressure monitoring capability, fully and reliably, into the existing vital signs monitor.

Several noisy environments in which this device might be used, have been identified, i.e. helicopters and vehicles used as field ambulances. More studies are recommended to quantify the possible interference these environments might have on the device, and make modifications to the design to lessen their effect. Following such modifications, prototypes of the complete vital signs monitor should be built in sufficient quantity for user evaluation.

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Annex A: The 68HC805B6 microcontroller features.

This appendix presents a summary of the 68HC805B6FN microcontroller:

- HCMOS Technology
- 6 kbytes of OTPROM or EPROM
- 176 bytes of RAM
- 368 bytes of bootstrap ROM
- 8 Channel analog to digital converter
- Serial communication interface (SCI)
- 16 bit timer subsystem
- External timer and SCI interface
- Fully static operation
- Computer operating properly (COP) watchdog timer
- 24 bidirectional I/O lines
- On-chip oscillator with RC or crystal/ceramic resonator mask operation
- 2 MHz internal operation at 5 volts; 1 MHz at 3 volts
- Single 3 to 6 volt supply
- Power-on and external reset
- 8×8 unsigned multiply instruction
- True bit manipulation
- Memory Map I/O
- Two power-saving standby modes (STOP and WAIT)
- 48-Pin DIP or 52-pin PLC (OTPROM) package
- 48-pin DIP (EPROM Window) package

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Monitoring of the vital signs of casualties in the field is an ongoing concern of the Canadian Forces Medical System. A vital signs monitor has been developed previously, which would measure heart rate and body temperature continuously and concurrently. In order to enhance the capabilities of the device, it was decided to investigate the feasibility of adding the capability of monitoring blood pressure. Using the oscillographic method of measuring cuff pressures, and the Erlanger procedure for determining systolic and diastolic pressures, several algorithms were tested for determining blood pressure. The design parameters were limited to the unused resources remaining in the existing monitor. A method of digitally sampling pressure pulses, using a two dimensional filter for determining pulse validity, and establishing systolic and diastolic blood pressure, is described.

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